Ask Dr. ALOHA:

Terrain effects in urban areas

Jacob Levy, a member of the New York City Fire Department's HazMat unit, uses ALOHA for emergency planning and hazard analysis. He is familiarizing himself with ALOHA 5.2, which he has just received. One of the first new features that he discovers is the Help button next to ALOHA's list of limitations.

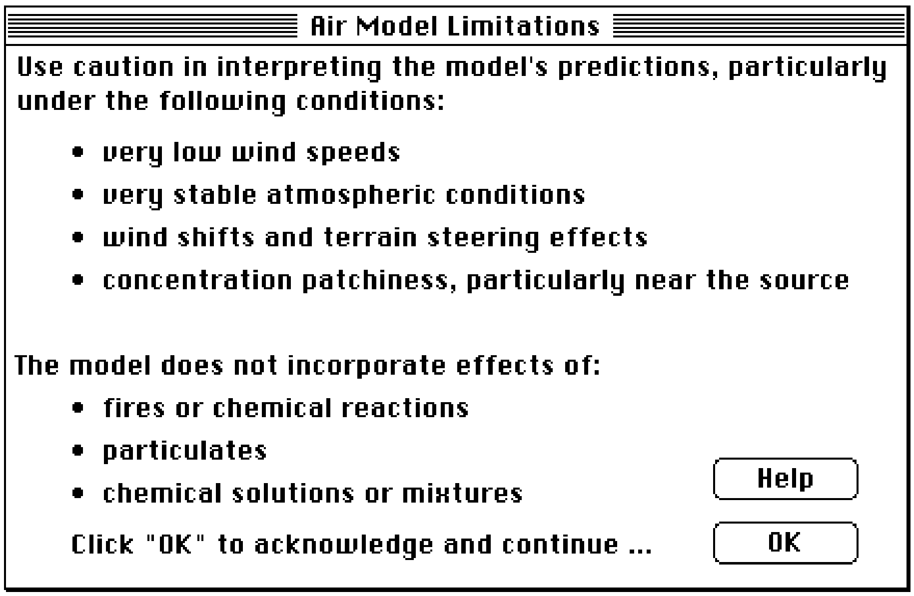

Figure 1. ALOHA's list of limitations.

He clicks the button, and finds detailed explanations of each item in the list.

Terrain steering

The third item in the list, "wind shifts and terrain steering effects" catches Jacob's attention. Here's what he reads about this topic after clicking the Help button:

> ALOHA assumes that wind speed and direction are constant (at any given height) throughout the area downwind of a chemical release. ALOHA also expects the ground below a dispersing cloud to be flat and free of obstacles. In reality, though, the wind typically shifts speed and direction as it flows up or down slopes, between hills or down into valleys, turning where terrain features turn. In urban areas, wind flowing around large buildings forms eddies and changes direction and speed, significantly altering a cloud's shape and movement. Through streets bordered by large buildings can generate a "street

canyon" wind pattern that constrains and funnels a dispersing cloud. ALOHA ignores these effects when it produces a footprint plot.

Jacob sees that when ALOHA makes its footprint calculations, it assumes first that the wind blows at a constant speed without changing direction, and second that the terrain below a toxic cloud is flat and free of obstacles. But downtown Manhattan, with its skyscrapers towering overhead, is hardly flat! He wonders: how different are ALOHA's predictions from what might really happen during an accidental release in an urban area?

The short answer is that no one can tell exactly how inaccurate ALOHA's predictions might be for such a release, because – for obvious reasons of public safety – no one has intentionally released gas in an urban area to study how gas clouds move and disperse inside cities. We can build our intuition about this question, though, by considering what happens when ALOHA's assumptions of constant wind and flat terrain are not met.

Wind flow in urban areas

Even if air flow into New York City is relatively steady and the winds predictable, ALOHA's first assumption is not likely to be met within the city itself. Buildings may block and divert the wind. Air flowing past large obstructions such as buildings forms into turbulent eddies, just as eddies form immediately downstream of a boulder or bridge piling in a river. Air flowing across an urban landscape composed of many buildings breaks up into irregular patterns of eddies of various sizes, speeds, and strengths. Winds blowing through city streets can speed up, slow down, and markedly change direction. In fact, wind blowing past an obstruction such as a building sometimes can completely reverse direction. A pollutant cloud released within a city therefore may be blown by the wind in a direction very different from the direction that ALOHA would predict. A cloud encountering the irregular air flow typical within a city may even be broken up into several clouds, each moving in a different direction.

Within the complex terrain of a downtown area, concentrations of gas can become very patchy for several reasons. Heavy gases can be trapped within low areas, such as stairwells, sunken terraces, empty swimming pools, and construction ditches and pits. Sometimes, wind eddies forming behind buildings can trap and recirculate gas, building pollutant concentrations in the lee of buildings to levels much higher than expected. But an opposite effect may sometimes occur: behind tall buildings, wind eddies may spiral upwards, lowering pollutant concentrations by drawing pollutant gas upwards and clean air downwards. ALOHA cannot predict any of these effects.

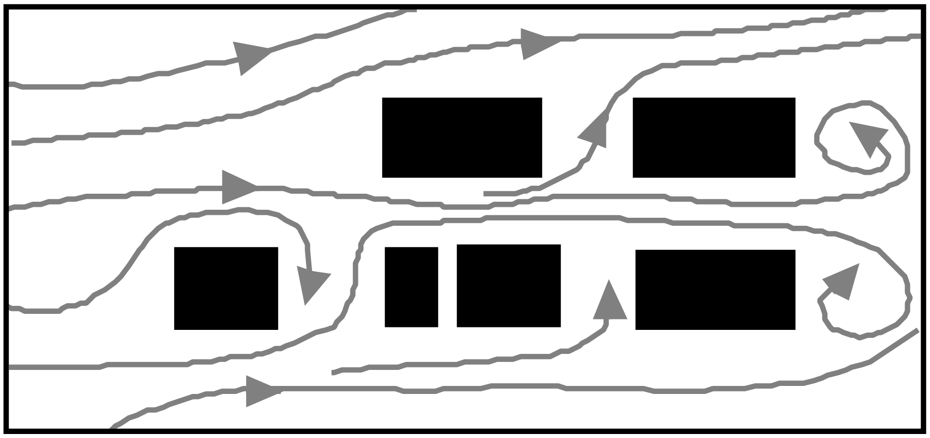

Figure 2. Within a city, air flow is irregular; wind can shift direction and form turbulent eddies.

New York City contains many “street canyons” – long, straight through streets bordered by tall buildings. A street canyon can funnel the wind at a speed and in a direction different from what a user may have entered into ALOHA. Similarly, it can act to channel a cloud. The cloud, prevented by the walls of buildings from dispersing in the crosswind direction, may travel much farther downwind than ALOHA would predict before diluting below the level of concern.

Heavy gas clouds, because they tend to spread outward rather than upward when they are unconfined, are especially likely to be channeled through street canyons or narrow valleys for long distances. An example of a real release in which heavy gas was channeled in this way was a sudden release in August 1986 of carbon dioxide that had built up in the depths of Cameroon’s Lake Nyos (researchers are still not sure what caused this release). A heavy cloud of carbon dioxide was channeled along a populated valley away from the lake. Because the cloud remained low in the valley, and was prevented from spreading outwards by the sloping walls of the valley, carbon dioxide concentrations within the cloud remained high enough to asphyxiate people as far as 10 kilometers away from the lake.

Obstacles and roughness elements

Responders and planners operating in urban areas should be aware of another issue that is important for dispersion modeling. To make footprint computations, ALOHA needs an estimate of ground roughness. It requires this information because friction between the ground and air passing over it causes mechanical turbulence. The greater the ground roughness, the greater the friction-induced turbulence, and the more quickly a pollutant cloud will be diluted by mixing with the air around it. ALOHA offers you two main choices of ground roughness – Open Country and Urban or Forest (you can also enter a specific roughness length if you wish). Its documentation directs you to choose Urban or Forest if the area has many friction-generating “roughness elements,” such as trees or small buildings (other examples are residential housing developments, industrial areas, or forests).

This seems straightforward, but there's an important twist. Depending on the size of a pollutant cloud, a feature such as a building may act as either a roughness element or an obstacle. If a building is large relative to the height of the pollutant cloud, it is probably an obstacle that would divert the cloud rather than a roughness element that would generate turbulence that would dilute the cloud. The skyscrapers of downtown Manhattan are so large that they are unlikely ever to be roughness elements (instead, they would be obstacles), but smaller buildings and trees may be, depending on the size of a release (Figure 3).

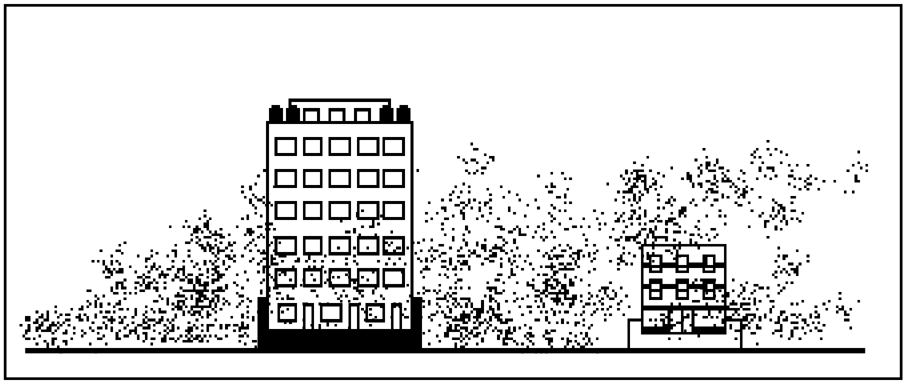

Figure 3. The large building on the left will act as an obstacle to the dispersing pollutant cloud; the smaller building on the right is likely to act as a roughness element instead.

The fact that you need to know something about the size of the pollutant cloud before knowing what might act as a roughness element can affect your choice of ground roughness category. For example, in a downtown area on a Sunday morning with no cars on the streets, the best roughness category for a small release may be Open Country. In this case, the buildings are obstacles and the street is the roughness the pollutant cloud will experience. During a busy workday, though, the best choice for the same area, with its streets now filled with parked and moving cars that would act as roughness elements, would probably be Urban or Forest.

Conclusions

There's no quantitative way to adjust results from a model like ALOHA for the effects of terrain. ALOHA's footprint and concentration estimates may not be very accurate for releases within large cities. Concentrations in some areas, especially within depressions (in the case of heavy gases) and in the lee of buildings, may be much higher or lower than ALOHA predicts. ALOHA's footprint may be an underestimate of the distance that could be covered by a cloud channeled down a through street. In some cases, changes in wind direction may cause the toxic cloud to travel in a different direction than ALOHA predicts – or the cloud might even break apart into several smaller clouds.

ALOHA can still be useful to you as a “ballparking tool” for urban response or planning, however.   It can be especially useful if you’re working with an unfamiliar chemical and need to answer questions like: Will Chemical X escape as a pressurized gas, or an evaporating liquid? Could it present an air hazard the size of many city blocks, or just a few square yards downwind of a puddle? As you use ALOHA, or any other model, just be sure to bear in mind not only its capabilities, but also its limitations.

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